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POTENTIAL WATER CONTAMINATION CAUSED BY THE USE OF MARINE MOTORS OF THE OUTBOARD TYPE

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POTENTIAL WATER CONTAMINATION

CAUSED BY THE USE OF

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By

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ABSTRACT

The Research Branch of the Ministry of the Environment has completed a literature review and laboratory study of potential water contamination by two-cycle outboard marine engines. Outboard motors were operated in tanks of water, with and without the engines modified to divert unburned fuel that is normally discharged into the water, to measure the quantity of contaminants discharged in the exhaust from these motors and their effects on the quality of water for different uses. The results of this study indicate that the operation of two-cycle outboard motors represents a potential source of pollution to lakes and rivers. The most significant pollution problem appears to arise from the effect of exhaust products on water odour and in the tainting of fish flesh. The quantity of water diluting the exhaust materials and the natural self-purification capacity of the receiving water are the major determinants regulating safe levels of outboard motor activity.

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1.0 SUMMARY

The use of outboard motors on pleasure boats in Ontario is increasing and there has been concern that the exhaust products from these engines may become a significant source of contamination of Provincial lakes and rivers. A study has been made, based on an evaluation of laboratory tank tests and published data, to measure the quantity of contaminants discharged in the exhaust from outboard motors and to determine their effect on the quality of water for different uses. Tests have been made with a pollution control device installed and with the engines operated as they would under normal operation. An investigation has also been made of an artificial impoundment to determine the effect of outboard motor activity on water quality under natural conditions.

Tank tests made with engines modified to divert crankcase drainage normally discharged into the water have shown that the amount of unburned fuel wasted ranged from less than 1 percent to over 27 percent of the original fuel drawn by the engine, varying with motor models and engine speed.

Algal growth experiments conducted in the laboratory have shown that the concentration of exhaust materials which would be experienced under normal field conditions, does not influence the growth of algae.

These studies, supported by the findings of English et al. (6, 7), show that the operation of two-cycle outboard marine engines represents a potential source of pollution of

lakes and rivers. The most significant pollution problems owing to two-cycle outboard motor activity appear to be water odour and the tainting of fish flesh. Gross loading data indicate that the quantities of exhaust products presently being discharged into the water do not generally exceed the objectives for water quality that have been adopted by the Ministry of the Environment.

2.0 INTRODUCTION

Motor boating has been a popular recreational activity in Ontario for over 40 years and the use of outboard motors on pleasure boats increases every year. Several studies have been made during the past 10 years on the subject of pollution from two-cycle outboard motors and it has been variously reported that from 0 to 56 percent of the fuel drawn by the engine is discharged unburned into the water. A conservative estimate of the present fuel wastage would be 10 percent of all outboard motor fuel used. Since approximately 10.7×10^6 gal. (49×10^6 l) of outboard fuel are sold annually in Ontario (estimated 1971 figure based on use of marine white and regular gasoline), the total amount of unburned fuel discharged by two-cycle outboard motors would be approximately 1.1 million gal. (4.9×10^6 l).

2.1 Water Contamination by Outboard Motors

Today, almost all of the outboard motors used on Provincial lakes and rivers are two-cycle models. With this design a mixture of gasoline and oil is used as a fuel and as a lubricant for the engine. The gasoline-oil-air mixture is valved directly from the carburetor into the crankcase which serves as the intake manifold. Because of temperature and pressure variations, centrifugal forces, friction, etc. a portion of the fuel-air mixture condenses within the crankcase. Most of the gasoline revaporizes since it is more volatile than oil, leaving a thin film of oil on the engine parts. This process goes on continually

while the engine is in operation. (1, 2)

Since the condensate is not drawn into the combustion chamber, it is not burned and thus begins to collect in the lower portions of the crankcase. If this liquid were allowed to accumulate in the crankcase it would build up to a point where the piston could not enter the crankcase in its downward stroke. This condition is commonly known as "hydraulic lock" and may cause engine damage. To avoid this condition the condensate or crankcase-drainage is vented from the crankcase via pressure-actuated valves into the exhaust system where it is discharged into the water. It has been reported that wastage of unburned fuel through the crankcase drain ranges from less than one percent to over 50 percent of the original fuel mixture used. (1-5)

The intake-exhaust system employed in two-cycle engines is another source of water contamination resulting from the operation of outboard motors. Unlike the four-cycle engine which uses separate piston strokes for intake and exhaust, the two-cycle engine combines intake and exhaust into one stroke. Since the exhaust and intake ports are open at the same time, some fresh unburned fuel vapour is lost through the exhaust port. This is one reason for the smokey exhaust from two-cycle engines and for the discharge of unburned gasoline and oil vapour. However, compared to the large amounts of liquid fuel being wasted from the crankcase, the amount of fresh fuel vapour lost via the exhaust ports is small. (1,2)

2.2 Purpose and Objective

Because of the increased usage of outboard engines there has been concern that the waste products from these engines may become a significant source of contamination of Provincial lakes and rivers. In July 1970, a reported oil slick in Belwood Lake was attributed to two-cycle marine motors. This subsequently resulted in a request that the Research Branch of the Ministry of the Environment investigate the impact outboard marine engines have on water quality.

A literature survey and laboratory study were made to determine the quantity of contaminants discharged from motors operated in test tanks, based on fuel consumed and engine speed. Tests were made both with and without a pollution control device attached to the engine. The control device collected fuel normally discharged from the crankcase into the water. Another objective of this study was to determine the effect of waste products from outboard motors on algal growth, as measured by chlorophyll a. Also, samples of Belwood Lake water were collected periodically during the summer boating season and examined for organic material, measured as carbon chloroform extracts (CCE), to ascertain if there was an increase in organic content that could be related to outboard motor operation.

3.0 LITERATURE SURVEY

Two of the earlier studies of pollution from outboard motors were made by English, Surber, McDermott, and Henderson in 1961. (6, 7) In a preliminary study, two outboard motors were operated in tanks of water in the laboratory. The outboard motors were 5.4- and 10-horse-power (HP) models operated in a 65-gal. (250 l) capacity stainless steel tank and a 500-gal. (1800 l) capacity aluminum tank, respectively. It was found that when the 5.4-HP motor was operated at constant speed, the accumulation of extractable hydrocarbons and oxidizable material in the exhaust water was approximately proportional to the length of time the motor was operated. This indicated that, "the sweeping out of these contaminants is minimal and that as contaminants accumulate there is no tendency to lower absorption rates by the water into which outboard motor exhaust is discharged". (6)

The analysis of samples collected for each test series included measuring volatile and non-volatile oils, lead, phenols and COD. The results indicated that for every gal. of fuel consumed, the following amounts of various contaminants are discharged to the exhaust water:

	126	grams of non-volatile oil
	68	grams of volatile oil
	0.64	grams of lead
	0.76	grams of phenols
and	519	grams of COD

Based on a figure of 3.12 grams of lead per gal. of gasoline (o.69 gm/l), approximately 21 percent of the lead in the fuel mixture was recovered in the exhaust water. A gasoline-to-oil ratio of 16:1 was used for the preliminary study (one-half pint of oil per gal. of gasoline).

Static bioassay tests using fathead minnows and bluegills were conducted to determine the acute and chronic toxicity of the exhaust water. A median tolerance limit (TLm) corresponding to the dilution at which 50 percent of the test animals survived for 96 hours was established at a level equivalent to approximately 143 gal. of fuel consumed per acre-foot of dilution water (527 $l/10^3 m^3$). However, samples of exhaust water that stood at room temperature for four days were non-toxic to fish indicating that the toxic effect fades rapidly with time. These experiments showed little chronic or accumulative effect on fish. In addition, experiments conducted to determine whether flesh of fish exposed to exhaust water would acquire an objectional flavour indicate that fish flesh will become tainted at a level estimated at 0.9 gal. of fuel consumed per acre-foot of dilution water (3.3 $l/10^3 m^3$).

The study also investigated the possible damaging effects of the exhaust products from outboard motors on the quality of water for domestic use and on conventional water treatment processes. The results indicate that the concentrations of the exhaust water likely to reach a domestic water treatment plant would not adversely affect conventional coagulation and sedimentation processes when alum is used. About 80 percent of the non-volatile oils

were removed by coagulation, sedimentation, and filtration; however, none of the volatile oils were removed by these processes. An increase in the threshold odour number of the exhaust water was noted when approximately one gal. of fuel was consumed per million gal. of water (1 $1/10^3m^3$). After treatment to remove odour by coagulation, sedimentation, filtration, and chlorination to a 0.5 mg/l combined chlorine residual, the threshold odour number of exhaust water equivalent to 750 gal. of dilution water per gal. (750 l/l) of fuel consumed remained unchanged at 480. However, this dilution level is unusually high (equivalent to 360 gal. of fuel consumed per acre-foot of water or 1327 $1/10^3m^3$) and is not indicative of conditions that would be found under normal field conditions. According to English et al., a surface area 200 feet by 200 feet (60m by 60m) appears to be the minimum for maneuvering a boat for recreational purposes. If an average lake water depth of 5 feet (1.5m), average motor operation at 2 hours per day, and an average fuel consumption of 0.5 gal. (2.27 l) per hour are assumed, the dilution level over a 90-day season would be equivalent to less than 20 gal. of fuel consumed per acre-foot of water (258 $1/10^3m^3$).

Following the laboratory study, English et al. carried out field experiments in three artificial impoundments, a motor lake, a motor pond, and a control pond, to determine whether fish are tainted or killed by outboard motor exhaust wastes under natural conditions. (7) Tainting of fish flesh was demonstrated and the threshold level at which tainting became evident corresponded to a fuel-use level of

approximately 2.2 gal. of fuel consumed per acre-foot of water ($8.1\ l/10^3m^3$) and a daily fuel-use rate of 0.046 gal. of fuel per acre-foot of water ($0.17\ l/10^3m^3$) for a 60-day boating season. The increase in threshold odour number of the water due to motor use was less than 0.5 per gal. of fuel consumed per acre-foot of water. Also, it was indicated that the concentration of CCE materials in the motor lake and motor pond water progressively increased during the test period as the cumulative quantity of fuel consumed by the outboard motors increased. A maximum CCE concentration of about 0.022 mg/l was indicated for each gal. (4.5 l) of fuel consumed per acre-foot of water. When motor operation was halted, however, the threshold odour number and the CCE concentration decreased.

In their field study, English et al. reported that a higher fuel use level (approximately 2.2 gal. per acre-foot or $8.1\ l/10^3m^3$) was attained before tainting of fish flesh was observed, as compared to the laboratory study where tainting was observed at a fuel-use level equivalent to about 0.9 gal. per acre-foot of water ($3.3\ l/10^3m^3$). The difference was attributed to the minimal time allowed for biological degradation of contaminants during the laboratory study and indicates that when applying contaminant loadings or fuel-use data to a particular area, the rate of assimilation by natural purification processes and factors such as temperature that may affect these processes should be considered.

Extensive laboratory and field studies on pollution by outboard motors have also been conducted by Kempf, Ludeman,

and Pflaum in Germany. (9) Initially, braking tests (9) were carried out to measure the quantities of waste gasoline, oil and combustion products discharged relative to the ratio of lubricating oil to gasoline in the fuel mixture. Three new two-cycle outboard motors were used, a 6-HP one-cylinder motor, an 18-HP two-cylinder motor, and a 40-HP two-cylinder motor. Also, tank tests were made with the 18-HP motor, using a gasoline to oil ratio of 50:1, to determine the quantities of oil, readily volatile hydrocarbons, lead, phenols, COD, and aldehydes discharged in the exhaust gases, and to determine threshold odour concentrations. In addition, bioassays were made to measure toxicity and tainting effects of combustion products. In a comparison of the 25:1 to 50:1 mixture ratios, it was found that the oil discharged decreased by 50 percent when the gasoline to oil ratio was increased. On the other hand, the advantage obtained with the 100:1 mixture was considered small, because a physically and chemically different lubricating oil had to be used. Reporting on basically the same contaminants mentioned in earlier studies made by English et al. it was indicated that the most significant problem arises from the effect of exhaust products on water odour and the tainting of fish flesh. Using a figure of 500 mg lead per litre of gasoline, Kempf et al. indicated that the lead recovered in the exhaust water represented about 8 percent of the lead in the original fuel mixture. This indicated that lead present in the anti-knock additive as tetra-ethyl lead mostly accumulates as lead oxide on the

interior walls of the engines and consequently they did not consider lead a significant contaminant. In general, because of the relatively low concentrations measured in the test waters, hydrocarbons, phenols and aldehydes also were not considered significant contaminants.

The results of laboratory tests to measure taste impairment of fish flesh were generally confirmed by field tests carried out in a test canal with a volume of approximately 6.7 acre-feet ($8.3 \times 10^3 m^3$), and an adjacent control canal which was used for comparison, about one-third the size of the test canal. The tainting of fish flesh was first observed one week after the start of the taste tests; the use of fuel corresponded to a dilution of approximately 2.7 gal. per acre-foot of water ($10\ l/10^3 m^3$). Tainting of fish flesh was severe at a level of approximately 10.8 gal. of fuel consumed per acre-foot ($40\ l/10^3 m^3$) and the test animals were generally considered inedible. As indicated by English et al., it was reported that taste impairment disappeared fairly rapidly after putting the fish back into uncontaminated water.

The results of bioassay tests carried out in aquaria indicated that the level of toxicity varies over a wide range depending on fish species. At a fuel-to-water dilution ratio of 1:2000 (136 gal. of fuel consumed per acre-foot of water or $501\ l/10^3 m^3$), carp were affected after a detention period of 2 hours and were killed within 26 hours; at a dilution ratio of 1:4000 death occurred after 44 hours. Trout were the most sensitive test animal; at a dilution ratio of 1:3000 (90 gal. of fuel consumed per acre-foot of water or $332\ l/10^3 m^3$)

the trout were affected after 40 minutes and death occurred after 75 minutes. In contrast, the test animals in the open test canal were not affected at a dilution ratio of 1:3000, and this was attributed to the evaporation and dispersion of certain toxic components.

Results of biological examination of the test canal to determine the extent to which outboard motor exhaust products have a detrimental effect on aquatic plants and animal organisms were considered inconclusive. Again, as found by English et al., (7) it was reported that after outboard motor operation was discontinued, the general quality of water in the test canal improved progressively with time as a result of self-purification processes. (9)

In summarizing, the authors concluded that the number of boats operating with outboard motors to be allowed on lakes and other water bodies should be determined with reference to the possible effects on use of the water as a source of drinking water supply and to the damage to fish stock and biological conditions. Based on the influence of outboard motor exhaust products on the taste of fish determined through field tests which confirmed data reported by English et al. earlier, they recommended a permissible fuel consumption for a summer season of 1.36 gal. of gasoline-oil mixture per acre-foot of water ($5\ l/10^3 m^3$) for a stationary body of water. They further recommend that boat operation with outboard motors on stationary waters scheduled directly for a supply of drinking water (e.g. reservoir) should be prohibited. (9)

Data on the toxicity of specific compounds contained in the exhaust from two cycle outboard marine engines are also contained in the literature. Jenkins (10) reported 8 - 29 mg/l phenols as the TLm for fathead minnows. According to Eckenfelder (11) the TLm for bluegills is 5.7 mg/l phenols and 55 mg/l for mosquito fish. Klein indicated that the threshold value for phenols at which fish flesh will become tainted is 25 mg/l. (12) Reporting on the toxicity of lead, Eckenfelder indicated the TLm for bluegills to be 0.2 mg/l lead when the metal was added as tetraethyl-lead, an organic lead compound. When inorganic lead was added instead the corresponding value was 5.6 - 11.5 mg/l in soft water and 482 mg/l when hard water was used for the test. Klein indicated aldehydes and hydrocarbons are lethal to fish at a concentration of approximately 50 mg/l and 10-20 mg/l, respectively. (12)

One study reported on tests made using a proprietary device that diverts the normal crankcase and cylinder drainage from the exhaust system into the fuel system thereby eliminating the discharge of unburned fuel into the water. This device was connected to the crankcase bleeder valves and blocked off the drain from the valve which allowed the unburned fuel to go into the exhaust system. Using crankcase pressure, the flow was redirected to a mixing chamber along with fuel drawn from the original mixture and immediately redirected to the motor. It was reported that the running time of a 33-HP motor, engaged in gear and using a test propeller, was increased by 68.8, 66.2, and 41.7 percent at 1000, 2000 and 3000 rpm respectively, with the pollution control device connected.

With the engine idling at 650 ± 100 rpm it was found that the device returned over 25 percent of the fuel drawn by the engine. (3)

Several studies have been made to determine the amount of unburned fuel discharged by two-cycle outboard marine engines. In 1969 Stillwell and Gladding (5) conducted tests using 5-, 33-, 40-, 50-, and 60-HP motors of different manufacture and model. All motors were operated at 1500 ± 100 rpm with standard test propeller in a test tank and using a gasoline to oil ratio of 50:1. All the motors were operated for five minutes prior to testing for warm-up, fuel exhausted from system, 32 ounces (0.95 l) of fuel mixture introduced, and motor run to run-out. The percentage of waste fuel was 1.57, 31.25, 31.25, 53.1 and 54.7 percent, respectively. These results agreed closely with the results reported by Stewart and Muratori (13) for similar engines.

A recent study made to measure the quantity of exhaust products discharged from two-cycle outboard engines as a function of operating time, water depth and engine speed was reported by Shuster in September 1971. (14) Tests were made at three engine speeds using an untuned 33-HP motor then with the same motor tuned. Studies were also made of the biodegradability of fuel and exhaust products from the operation of outboard engines. Tests made with the engine untuned resulted in fuel wastage figures up to 15 percent greater than those obtained from the same engine after tune-up. With the engine untuned the quantity of fuel wasted varied from about

7 percent of the volume of fuel used at high speed, to over 30 percent at low speeds.

The biodegradability studies indicated that the 50:1 engine fuel mixture, as well as exhaust products, are capable of supporting microbial growths. Growth rates with fresh fuel mixtures were less than with engine exhaust products; this difference was attributed to higher concentrations of volatile gasoline components. It was indicated however, that growth rates and consequently purification rates, are limited by available oxygen. This means that if the utilization of dissolved oxygen in the biological degradation of the organic substances exceeds the reaeration capacity of the receiving water, stabilization of these compounds will be reduced and, thus, contaminants would accumulate.

The results obtained from field studies conducted by Environmental Engineering, Inc., in 1969 (15) appear to contradict many of the findings of previous studies of pollution from outboard motors. A water quality survey conducted during a seven-month period of two adjoining lakes, a motor lake used extensively by a major outboard motor manufacturer as a testing ground for two-cycle outboard motors and a control lake which was "virtually undisturbed", indicated minor pollution resulted from outboard motor operation. The test lake has an average depth of 12 feet (4 m), and a volume of 16,800 acre-feet ($13.6 \times 10^3 m^3$). Because of the comparatively large size of the lake studied, the results obtained by Environmental Engineering, Inc. may be more representative of what could be

expected in the field in a fair size lake (as opposed to the ponds used by English et al. (6, 7)

The report indicates that during a 10-year period approximately 2.5×10^6 gal. (11.4×10^6 l) of fuel were used for outboard motor operation on the test lake; during the 3-year period previous to the study fuel consumption averaged approximately 295,000 gal. (1.3×10^6 l) per year. This is equivalent to an annual fuel consumption level of 17.6 gal. per acre-foot (65 $l/10^3m^3$) or a continuous daily fuel consumption level of 0.048 gal. per acre-foot (0.18 $l/10^3m^3$). It is important to note that this continuous daily fuel consumption level is approximately one order of magnitude greater than the level indicated by English et al. (7) and Kempf et al. (9) (0.07 $l/10^3m^3$) that is permissable over a 60-day season to control odour.

In the Environmental Engineering, Inc. study, the control lake, which is about one-quarter the size of the test lake, drains into the test lake and there is reportedly no contamination. Samples collected from the test lake and the control lake were analysed for nutrients, COD and organic compounds characteristic of exhaust emissions from two-cycle outboard marine engines. Examination of water and sediment samples from both lakes by gas chromatography did not reveal any contamination by hydrocarbons found in outboard motor exhaust water. Compared to the control lake there were no observable differences in the chemical quality of the test lake and when compared to other lakes of similar characteristics it

was concluded that no pollution had occurred. These results suggest that organic compounds discharged in the exhaust from outboard motors are readily assimilated by the natural processes in the lake system and do not necessarily create a pollution problem if the use rates are not excessive.

Biological studies were also carried out in both lakes. After removing one extraneous source of contamination, bacterial counts were reported to range between 20 and 800 per ml and generally there was no observable effect on phytoplankton or benthic organisms. At one location used for docking and fueling operations, algal productivity was reduced and there was an absence of benthic organisms in the samples collected from this area, indicating the water quality was significantly impaired. These results demonstrate that local contamination can be significant at fueling stations where large quantities of gasoline and oil are spilled through careless operation. (15)

A series of bioassay tests using bluegill sunfish were conducted in order to establish a median tolerance limit for outboard motor exhaust water. Although a TLm was not established, the tests did demonstrate the toxicity of exhaust products discharged into exhaust water. The concentration necessary to achieve a fish kill however, was excessively high and would not normally be experienced under natural conditions (approximately 1000 gal. (4546 l) fuel consumed per acre-foot of water). (15)

4.0 METHOD OF STUDY

For the Research Branch laboratory study, tank tests were conducted on 4-, 6-, 9.5-, and 40-HP two-cycle outboard marine engines of different manufacture to determine the quantities of contaminants discharged based on fuel consumed and engine speed. Test runs were made on 9.5- and 40-HP motors both with the crankcase drainage collected by a by-pass tube device, and with it discharged to the water as it would under normal operation. Although diverting the waste fuel or crankcase drainage from the exhaust is straight forward on some engine models, there are some models that must be disassembled to make the modification. The 6-HP motor tested could not be readily modified. With considerable difficulty, the 4-HP motor was modified by inserting a blank and by-pass device to divert a major portion of the waste products discharged in the exhaust; the diverted exhaust gases were then collected by scrubbing in an 18 l volume of tap water.

Algal growth studies were made using water from Lake Ontario in which the 4-HP motor was operated both with the motor modified to divert a portion of the exhaust products, and with the exhaust discharged to the water in the test tank as it would be under normal operation. The 6-, 9.5-, and 40-HP motors were tested using tap water.

The 4-HP motor was operated in a 45 gal. (200 l) capacity epoxy coated steel drum, 0.6 m in diameter and 0.85 m deep. The 6-, 9.5-, and 40-HP motors were operated in a 240 gal. capacity galvanized steel and wood tank, 1.2 m by 1.06 m deep (1450 l liquid volume). The inside walls of the large test tank were coated with a lead-free interior/exterior white enamel paint.

Prior to each run, the motor being tested was operated at test conditions for approximately 5 minutes in a separate warm-up tank, the fuel exhausted from the system, the motor lifted, cleaned, and then transferred to the test tank. At the start of each test run a measured volume of fuel was introduced, then the motor operated to run-out. When possible each motor was operated with the engine at idle and engaged in forward gear at three rpm levels. The 9.5- and 40-HP motors, because of violent mixing of the tank contents at high speeds, were not operated at full throttle. No attempt was made to tune the engines during the study. One run on the 40-HP motor was repeated however, after an oil seal in the motor's drive unit failed and was replaced. The fuel mixture consisted of a regular grade, leaded, motor gasoline and a two-cycle outboard motor lubricating oil that had a high ash content. A fuel ratio of 40 parts gasoline to one part lubricating oil (40:1 ratio) was used during the study.

4.1 SAMPLING PROCEDURE

Samples of water were taken before and after each test run by dipping one litre sample bottles under the surface of the water during turbulent mixing of the tank contents. Samples of water for phenol and carbon determinations were taken in the same manner using 500 ml. glass-stoppered flasks. In the runs in which the crankcase drainage was collected, the waste was discharged into a one litre sample bottle, the liquid weighed and the volume measured for each test run. After each run the test tank was cleaned with detergent and thoroughly rinsed using tap water.

5.0 ANALYTICAL PROCEDURE

5.1 CHEMICAL ANALYSIS

Samples of raw water and exhaust water were analysed for COD, phenols, carbon, nitrogen, and phosphorus according to Standard Methods. (16) The total lead determination consisted of wet digesting the sample in aqua regia and then aspirating directly into the flame of an atomic absorption unit. Organic lead analyses were carried out on some samples by extracting into iso-octane and then aspirating directly into the flame of an atomic absorption unit.

The quantities of volatile and non-volatile oils were determined by acidifying the sample and then extracting with carbon tetrachloride. Following filtration through a fiberglass filter paper to remove emulsified water and any precipitates that were formed, the extract was analyzed by infrared technique. The spectrum obtained was then compared to a standard solution, prepared using 37.5 percent iso-octane, 37.5 percent hexadecane, and 25 percent benzene in carbon tetrachloride, to measure the quantity of volatile oils. The residue obtained from the extract after vacuum distillation at 90^{o}C and 20 inches vacuum for 2 hours was weighed to give the weight of non-volatile oils.

5.2 ALGAL GROWTH EXPERIMENT

In order to determine the effect which exhaust products from outboard motors have on algal growth, the 4-HP motor was operated in tanks of Lake Ontario water at three speed levels both with the motor modified to divert a portion

of the exhaust into an 18 l volume of tap water, and with the exhaust discharged into the lake water in the test tank. After each test run, measured volumes of exhaust water from the test tank were placed in 3 l jars under artificial light in the laboratory for a period of about 14 days. A dilution series was prepared for each test run using Lake Ontario water of fuel-to-water ratios of approximately 1:100, 1:10,000 and 1:100,000. Water from Lake Ontario was used as a control for comparison of algal growth. No attempt was made to agitate the samples during the growth period to keep the algae in suspension. After about 14 days, because of evaporation, sample volumes were made up to the original volume using distilled water. Each sample was stirred in a blender for about 20 seconds to develop a uniform algal suspension and then a measured volume was filtered through 1.2×10^{-3} mm Millipore* filter. Chlorophyll a was determined for each sample according to Standard Methods (16) to measure algal growth. Samples of tap water used to collect the exhaust gases from the first series of test runs were analyzed for volatile and non-volatile oils, COD, lead, and organic carbon.

5.3 BELWOOD LAKE STUDY

During July and August, 1971, a study was carried out on Belwood Lake, an artificial impoundment which contains about 1800 acres ($7.3 \times 10^6 m^2$), as part of the general study of pollution from two-cycle outboard marine engines. During the 1970

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* Millipore Filter Corporation, Bedford, Massachusettes, U.S.A.

summer boating season, there was a report of an oil slick in Belwood Lake, presumably caused by the operation of outboard type engines. An investigation of the lake area shortly after the report of an oil slick was received was inconclusive.

Data from a study conducted by English et al. (6) indicated that the organic material discharged from outboard motors is partially oxidized, and is composed almost entirely of long-straight-chain aliphatic hydrocarbons with a trace of aromatic hydrocarbons. (6) Because this organic material shows up in the carbon chloroform extracts, any change in the organic content of water in which outboard motors are operated should be detectable by monitoring the concentration of CCE material. During the summer boating season, organic material in Belwood Lake water was recovered by activated carbon adsorption. Automatic samplers were installed at two locations along the lake shoreline, a measured volume of water was pumped through a sand filter to remove sediment and algae and then passed through a 2.5 l capacity carbon column. The carbon was air-dried in an oven at 40°C overnight, then extracted with chloroform into a Soxhlet extractor. After the chloroform was evaporated, the residue was weighed to give the weight of CCE material.

6.0 RESULTS

Fourteen runs on 6-, 9.5- and 40-HP motors were made in the 1450 l capacity test tank using tap water and six runs on the 4-HP motor were made in the 200 l capacity coated steel test tank using Lake Ontario water. These runs were grouped into seven series of tests depending on which motor was used and whether the motor was operated with or without a pollution control device. A summary of the operating data for each test run is given in Table I. A photograph of the test apparatus is shown in Figure I.

Results of the test conducted using the 40- and 9.5-HP motors to determine the percentage of fuel wasted are shown in Table II together with the analysis of the crankcase drainage. The analysis of the scrubbing water from the 4-HP motor is reported in Table III.

The concentration of contaminants measured in the raw water and the exhaust water is shown in Table IV and the weight of certain contaminants recovered in the exhaust water is shown in Table V.

Chlorophyll a measurements for the algal growth experiment are reported in Table VI for the six test runs on the 4-HP motor and the results of algal enumeration and identification tests made on samples of exhaust water from run 20 after the 14-day incubation period are shown in Table VII.

The results of CCE measurements on Belwood Lake water samples are shown in Table VIII.

TABLE I

SUMMARY OF OPERATING CONDITIONS FOR TANK TEST EXPERIMENTS

MOTOR RUN NUMBER	MODE OF OPERATION	POLLUTION CONTROL DEVICE	WATER VOLUME IN TANK (litres)	DURATION OF RUN (min)	MOTOR SPEED (rpm)	FUEL VOLUME USED (litres)
40-HP						
I - 1	Idle	yes	1126	27	815	2
- 2	Drive	yes	1159	29	690	2
- 3	Drive	yes	1163	21	1385	2
II - 4	Idle	no	1157	32	830	2
- 5	Drive	no	1157	35	620	2
- 6	Drive	no	1142	21	1410	2
9.5-HP						
III - 7	Idle	yes	1142	34	1425	1
- 8	Drive	yes	1159	36	1105	1
- 9	Drive	yes	1138	28	1915	1
IV - 10	Idle	no	1085	30	1480	1
- 11	Drive	no	1126	33	1035	1
- 12	Drive	no	1136	26	1965	1
6-HP						
V - 13	Drive	no	1109	73	955	1
- 14	Drive	no	1109	81	1732	1
4-HP						
VI - 15	Drive	yes	135	72	1125	1
- 16	Drive	yes	130	58	2035	1
- 17	Drive	yes	113	25	2650	1
VII - 18	Drive	no	143	110	1085	1
- 19	Drive	no	140	51	2055	1
- 20	Drive	no	125	25	2365	1

6.1 PERCENTAGE WASTE FUEL

The data shown in Table II for the 40-HP motor indicate that an increase in engine speed decreased the amount of fuel wasted. Also, there is only a small difference in the amount of fuel wasted at idle and with the engine engaged in forward gear at low speed. Although the fuel wastage indicated for the 9.5-HP motor is negligible compared to the wastage from the 40-HP motor, again more fuel was wasted at the low engine speed and at idle compared to the volume wasted at the higher speed.

In a comparison of the original fuel mixture (40:1 ratio) and the waste fuel mixture discharged from the crankcase of the 40-HP motor (Table II) it can be seen that the fraction of lubricating oil (non-volatile oils) contained in the crankcase drainage increased from 2.5 percent in the original fuel mixture to about 10.7 percent in the waste fuel. Also, the proportion of lubricating oil in the crankcase drainage increased with an increase in engine speed. The increase in density shown in Table II is indicative of the heavier gasoline to oil mixture in the waste fuel compared to the original fuel mixture. Similar test analyses were not carried out on the crankcase drainage from the 9.5-HP motor because of the small volumes collected.

6.2 TANK TESTS

6.2.1 General

During the laboratory study it was found that it was

TABLE II

RESULTS SHOWING PERCENTAGE WASTE FUEL AND ANALYSIS OF CRANKCASE DRAINAGE[1]

MOTOR USED: 40-HP at 4500 rpm

RUN NUMBER	ENGINE SPEED (rpm)	FUEL USED (litres)	FUEL RECOVERED (litres)	PERCENT FUEL WASTED	CRANKCASE DRAIN FLUID		
					DENSITY (gm/ml)	PERCENT NON-VOLATILE	VOLATILE
1	815	2	0.550	27.5	0.809	9.9	90.1
2	690	2	0.555	27.75	0.826	10.3	89.7
3	1385	2	0.210	10.5	0.818	12.1	87.9

MOTOR USED: 9.5-HP at 4500 rpm

RUN NUMBER	ENGINE SPEED (rpm)	FUEL USED (litres)	FUEL RECOVERED (litres)	PERCENT FUEL WASTED
7	1425	1	0.0066	0.66
8	1105	1	0.0030	0.30
9	1915	1	0.0010	0.10

Note: 1. Gasoline to oil ratio 40:1 equivalent to 2.5 percent non-volatile oil. Density of fuel mixture 0.713 gm/ml.

sometimes difficult to collect representative samples of exhaust water at the conclusion of each test run because a portion of the waste fuel discharged into the water tended to separate and accumulate in pools on the surface and coat the walls of the test tank above the waterline. When a pollution control device was used to divert the crankcase drainage the water-fuel mixture in the test tank usually formed a comparatively stable emulsion and the separation of these components was not nearly as noticeable. The photograph shown in Figure 2 was taken at the conclusion of run 6, after the mixers were shut off, to emphasize the coating on the walls of the test tank while the photograph shown in Figure 3 was taken at the conclusion of run 3 which was made at about the same speed as run 6 but with a device installed to collect the crankcase drainage. The change in appearance of samples of water in which outboard motors were operated, with and without a pollution control device installed, is illustrated in Figure 4. The sample 4H-R3 is a sample of scrubbing water collected during run 17 made using the 4-HP motor. Because of this tendency of the oily components to separate at the water surface of the test tank, it should be emphasized that the concentration of contaminants measured in the exhaust water (Table IV) and the weight of the various contaminants recovered (Table V) are considered to be conservative estimates of the quantities actually discharged during operation of the motor.

The data shown in Table V(b) illustrate that the loss of volatile compounds was significant when the 40-HP motor was operated without a pollution control device

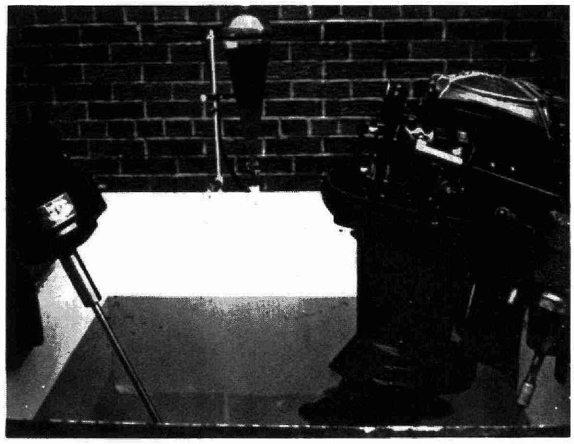


FIGURE 1. Test apparatus showing 1450 litre capacity test tank filled with tap water with the 40-HP motor mounted prior to run 2.

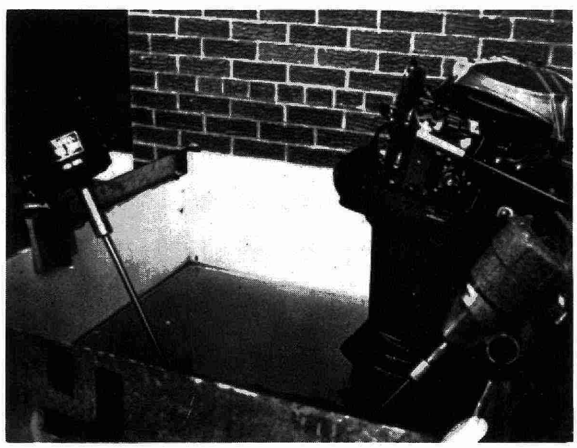


FIGURE 2. An illustration of oil coating on walls of test tank at the conclusion of run 6 made with the 40-HP motor operated as it would under normal operation.

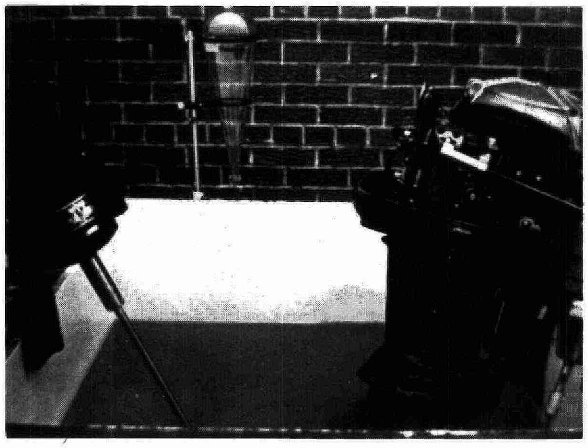


FIGURE 3. An illustration of the reduction in the level of oil contamination when the 40-HP motor was operated with a control device to prevent the discharge of crankcase drainage.

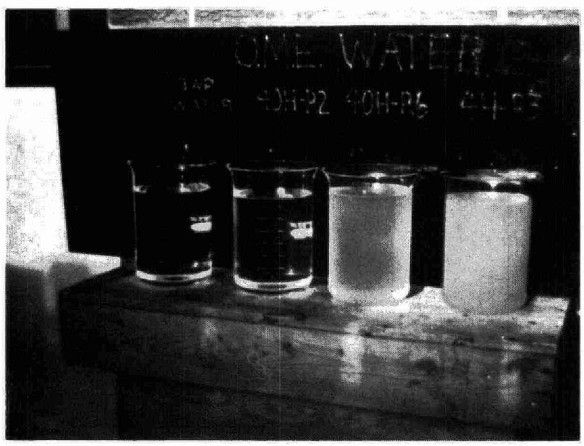


FIGURE 4. Samples of exhaust water showing the change in appearance of tap water in which the 40-HP motor was operated, with (40H-R2) and without (40H-R6) a control device, and condensate water (4H-R3) obtained from run 17 made using the 4-HP motor.

TABLE III

ANALYSIS OF SCRUBBING WATER OBTAINED FROM 4-HP MOTOR SHOWING CONCENTRATION AND TOTAL WEIGHT OF CONTAMINANTS RECOVERED

(a)

CONCENTRATION, mg/l

RUN NUMBER	15	16	17
pH	7.0	7.6	7.2
NON-VOLATILE OILS	323	303	348
VOLATILE OILS	855	26	468
LEAD	8.2	2.2	3.9
COD	2450	880	1500

(b)

TOTAL WEIGHT RECOVERED, grams

NON-VOLATILE OILS	5.81	5.45	6.26
VOLATILE OILS	15.39	0.47	8.42
LEAD	0.15	0.04	0.07
COD	44.1	15.84	27.0

and the crankcase drainage was discharged directly into the water in the test tank. If based on the assumption that 100 percent of the volatile oils discharged during run 3 was contained either in the crankcase drainage that was collected or in the exhaust water then the weight of volatile compounds recovered in the exhaust water during run 6 represents less than 18 percent recovery of the volatile oils actually discharged in the exhaust. Because of the lower boiling points, the volatile compounds tend to volatilize more readily due to the turbulent mixing in the test tank compared to the non-volatile compounds and consequently the loss of the volatile compounds was very high. The quantity of non-volatile compounds was very likely lost in the coating on the walls of the test tank.

With the 4-HP motor, on the other hand, the loss of exhaust material was generally greater for the runs made using a pollution control device. The loss of volatile compounds was likely due to the turbulent mixing of the scrubbing water which was caused by the passage of exhaust gases through the scrubbing water. Also, it was difficult to obtain representative samples of the scrubbing water because the oily components tended to form a coating on the walls of the recovery bottle. In addition it was necessary to submit separate samples for each determination so that the particular analysis could be made using the whole sample. The reproducibility was very low when several analytical determinations were made using the same sample.

6.2.2 Chemical Results

The concentration of contaminants measured in the

TABLE IV

CHEMICAL ANALYSIS OF RAW TAP WATER AND EXHAUST WATER [1]

(Units are mg/l except pH and threshold odour number)

MOTOR	RUN NUMBER	SAMPLE	pH	OILS NON-VOLATILE	OILS VOLATILE	PHENOLS	LEAD	COD	TOTAL PHOSPHORUS	ORGANIC NITROGEN	CARBON TOTAL	CARBON ORGANIC	CARBON INORGANIC	THRESHOLD ODOUR NUMBER
4-HP	15		-	0	0	0	< 0.05	< 30	0.22	0.63	27	6	21	-
	16		-	0	0	0.002	< 0.05	< 30	0.027	0.25	26	5	21	-
	17	Lake	-	0	0	0	< 0.05	< 30	0.20	0.63	27	6	21	-
	18	Water	8.0	0	0	0.005	< 0.1	< 30	1.1	0.8	40	9	31	-
	19		8.2	0	0	0.006	< 0.1	< 30	0.95	0.7	39	9	30	-
	20		8.0	0	0	0.006	< 0.1	< 30	1.1	0.9	40	7	31	-
	15		-	28.1	29.9	0.375	4.4	280	0.25	1.19	370	350	20	-
	16		-	22.6	24.8	0.15	0.35	90	0.07	0.42	58	33	25	-
	17	Exhaust	-	35.2	8.4	0.225	0.82	280	0.23	1.09	120	77	43	-
	18	Water	6.9	83.4	48.6	1.5	2.0	370	1.2	1.3	188	148	40	-
	19		6.9	82.4	44.6	1.5	1.6	420	1.1	0.8	235	215	20	4100
	20		7.3	173.9	85	2.0	3.9	1350	1.5	0	655	620	35	-
6-HP*	13	Tap	7.5	-	-	0.002	< 0.05	< 30	0.029	-	26	4.5	21	-
	14	Water	8.2	-	-	0.002	< 0.05	< 30	0.019	-	26	1.0	25	-
	13	Exhaust	7.1	-	-	0.25	< 0.05	160	0.025	-	89	59	30	-
	14	Water	7.3	-	-	0.25	< 0.05	90	0.02	-	53	25	28	8200

NOTE: 1. Exhaust water refers to water in which outboard motors were operated. Dilution volumes are reported in Table I.

* Non-volatile and volatile oils were not determined for 9.5- and 6-horsepower (HP) motors.

Cont'd ...

TABLE IV (Cont'd)

MOTOR	RUN NUMBER	SAMPLE	pH	OILS NON-VOLATILE	OILS VOLATILE	PHENOLS	LEAD	COD	TOTAL PHOSPHORUS	ORGANIC NITROGEN	CARBON TOTAL	CARBON ORGANIC	CARBON INORGANIC	THRESHOLD ODOUR NUMBER
9.5-HP*	7		-	-	-	0.002	< 0.05	< 30	0.12	0.46	27	7	20	-
	8		-	-	-	0.002	< 0.1	< 30	0.03	0.25	26	5	21	-
	9	Tap	8.1	-	-	0.002	< 0.1	< 30	0.028	0.20	30	10	20	-
	10	Water	8.1	-	-	0.002	< 0.1	< 30	0.039	0.22	25	5	20	-
	11		7.9	-	-	0.002	< 0.1	< 30	0.029	0.21	26	5	21	-
	12		8.0	-	-	0.002	< 0.1	< 30	0.036	0.13	25	6	19	-
	7		-	-	-	0.35	0.24	120	0.11	0.87	43	22	21	-
	8		-	-	-	0.35	0.28	120	0.053	0.22	77	46	31	-
	9	Exhaust	6.9	-	-	0.60	0.28	70	0.06	0.28	51	22	29	4100
	10	Water	7.5	-	-	1.00	0.17	60	0.043	0.24	44	11	33	-
	11		6.9	-	-	1.25	0.35	140	0.04	0.25	73	47	26	8200
	12		6.8	-	-	1.25	0.12	130	0.064	0.22	61	36	25	-
40-HP	1		7.6	0	0	0.004	< 0.1	< 30	0.032	0.20	27	6.5	20	-
	2		7.8	0	0	0	< 0.1	< 30	0.022	0.17	25	5.0	20	-
	3	Tap	8.0	0	0	0.002	< 0.1	< 30	0.032	0.26	25	7.0	18	-
	4	Water	8.0	0	0	0.004	< 0.05	< 30	0.029	0.20	25	5.0	20	-
	5		7.9	0	0	0.003	< 0.1	< 30	0.024	0.17	26	6.0	20	-
	6		7.9	0	0	0.003	< 0.1	< 30	0.026	0.26	25	7.0	18	-
	1		7.4	< 5.0	< 1.14	0.225	< 0.1	30	0.04	0.24	34	14	20	1024
	2		6.9	< 5.0	< 5.5	0.125	< 0.1	45	0.027	0.26	49	19	30	1024
	3	Exhaust	6.6	9.9	11.9	0.4	< 0.1	65	0.048	0.26	60	31	29	1024
	4	Water	7.4	48.35	61.35	0.5	0.46	245	0.042	0.22	184	160	24	8200
	5		6.8	56.7	75.1	0.4	0.5	290	0.03	0.19	195	170	25	8200
	6		6.5	38.5	32.0	0.5	< 0.1	245	0.05	0.14	100	83	17	8200

TABLE V

WEIGHT OF EXHAUST MATERIALS RECOVERED IN EXHAUST WATER, grams

MOTOR	RUN NUMBER	OILS NON-VOLATILE	OILS VOLATILE	PHENOLS	LEAD	COD	TOTAL PHOSPHORUS	ORGANIC NITROGEN	CARBON TOTAL	CARBON ORGANIC	CARBON INORGANIC
40-HP	1	ND*	ND	0.248	< 0.1	< 34	0.009	0.045	8.5	8.5	0
	2	ND	ND	0.145	< 0.1	< 52	0.006	0.104	27.8	16.2	11.6
	3	11.51	13.84	0.463	< 0.1	< 76	0.019	0	40.7	28	12.7
	4	55.94	70.98	0.573	< 0.525	< 284	0.015	0.024	184	179.3	4.7
	5	65.5	86.0	0.460	< 0.468	< 336	0.007	0.023	195.7	190	5.7
	6	44.0	36.54	0.568	< 0.1	< 280	0.030	0.178	85.6	86.8	-1.2
9.5-HP	7	-	-	0.398	< 0.274	< 137	-0.011	0.469	18.3	17.1	1.2
	8	-	-	0.408	< 0.325	< 139	0.026	-0.035	59.1	47.5	11.6
	9	-	-	0.678	< 0.239	< 80	0.029	0.019	24.3	13.7	10.6
	10	-	-	1.088	< 0.185	< 65	0.005	0.021	20.6	6.5	14.1
	11	-	-	1.408	< 0.344	< 158	0.012	0.046	52.9	47.3	5.6
	12	-	-	1.418	< 0.239	< 148	0.032	0.102	40.9	34.1	6.7
6-HP	13	-	-	0.026	ND	< 177	-0.004	-	70.4	60.4	10
	14	-	-	0.026	ND	< 100	0.001	-	30	26.6	3.4
4-HP	15	3.79	5.39	0.051	< 0.483	< 38	0.004	0.076	46.3	46.4	-0.1
	16	2.94	3.22	0.019	< 0.039	< 12	0.005	0.023	4.2	3.6	0.6
	17	3.98	0.95	0.025	< 0.087	< 32	0.003	0.052	10.5	8	2.5
	18	9.71	6.95	0.213	< 0.272	< 53	0.012	0.072	21.2	19.8	1.4
	19	11.54	6.24	0.209	< 0.210	< 59	0.021	0.014	27.4	28.8	-1.4
	20	21.74	35.63	0.248	< 0.476	< 169	0.048	-	76.9	76.4	0.5

NOTE: * Not Determined

TABLE V (b)

MATERIAL BALANCE SHOWING TOTAL WEIGHT OF NON-VOLATILE OILS AND VOLATILE OILS RECOVERED DURING OPERATION OF THE 40-HP MOTOR AND THE 4-HP MOTOR BOTH WITH AND WITHOUT A POLLUTION CONTROL DEVICE INSTALLED

MOTOR- RUN NUMBER	METHOD OF COLLECTION[1]	WEIGHT RECOVERED, grams NON-VOLATILE OILS	VOLATILE OILS
40-HP			
Run 1	D	44.1	401.1
	e	5.6*	1.3*
	D + e	49.7	402.3
Run 4	E	55.9	71.0
Run 2	D	47.4	412.6
	e	5.8*	6.4*
	D + e	53.2	419.0
Run 5	E	65.5	86.8
Run 3	D	20.8	189.2
	e	11.5	13.8
	D + e	32.3	203.0
Run 6	E	44.0	36.6
4-HP			
Run 15	S	5.8	15.4
	e	3.8	5.4
	S + e	9.6	20.8
Run 18	E	9.7	7.0
Run 16	S	5.5	0.5
	e	2.9	3.2
	S + e	8.4	3.7
Run 19	E	11.5	6.2
Run 17	S	6.3	8.4
	e	4.0	1.0
	S + e	10.3	9.4
Run 20	E	21.7	35.6

Note: 1. D - Crankcase drainage.
e - Exhaust water obtained with a control device installed.
E - Exhaust water obtained without a control device installed.
S - Scrubbing water.
* Estimated values.

exhaust and the raw water, shown in Table IV, indicate the incorporation of a pollution control device with the 40- and 4-HP motors significantly reduced the quantity of contaminants contained in the exhaust water. This effect is also illustrated in Table V which shows the weight of certain contaminants recovered in the exhaust water. From the results shown for the 40-HP motor operating without a pollution control device (Table V, runs 4, 5 and 6), an average of approximately 0.20 gm of lead and 0.269 gm of phenols were recovered per litre of fuel consumed whereas with the device installed (Table V, runs 1, 2 and 3) less than 0.05 gm of lead and 0.144 gm of phenols were recovered, a reduction of 75 and 46 percent respectively. Similarly, the weight of volatile and non-volatile oils, COD, organic nitrogen, total phosphorus and organic carbon recovered also decreased by 91, 84, 82, 34, 35, and 88 percent respectively when the pollution control device was used compared to the weights recovered when the crankcase drainage discharged into the water as it would under normal operation. Similar results are indicated for the 4-HP motor. Except for organic nitrogen which remained unchanged, the weights of the exhaust materials recovered, namely volatile and non-volatile oils, COD, lead, phenols, total phosphorus and organic carbon were reduced by over 80 percent. From the data shown in Tables III and V it will be noted that the discharge of contaminants during run 15 was high compared to runs 16 and 17. After run 15 was completed it was found that one of the spark plugs was shorting out and consequently combustion was incomplete. Therefore the level of contamination indicated does not represent "normal" conditions.

There was comparatively little difference in the weight of the various contaminants measured in the exhaust water from the 9.5-HP motor except for phenols which were reduced by approximately 62 percent when the pollution control device was used. This is consistent with the relatively small volumes of waste fuel recovered and shown in Table II.

The data shown in Table V indicate a generally higher pollution loading with lower engine speeds if based on the weight of contaminants recovered in the exhaust water. This is reflected in the comparatively high percentage of waste fuel recovered at the lower speeds and at idle (Table II). With the 40-HP motor operating without a pollution control device, the weight of lead recovered in the exhaust water decreased from 0.29 gm per litre of fuel consumed at 620 rpm (run 5) to less than 0.05 gm per litre of fuel consumed at 1410 rpm (run 6). The weight of volatile and non-volatile oils, COD and organic carbon recovered also decreased by 33, 31, 16, and 52 percent respectively, while the weight of phosphorus, organic nitrogen and phenols increased by 200, 110, 23 percent at the high rpm level compared to the results at the low rpm level. It is anticipated that the discharge of contaminants in general would be further reduced with motors operating at or near full load.

The data reported in Table V indicate that total carbon and organic carbon results show a definite increase with engine operation whereas the inorganic carbon results show only a small increase. This suggests that the increase of total carbon was mainly due to the volatile and non-volatile hydrocarbons discharged into the exhaust water.

TABLE VI

CHLOROPHYLL a ANALYSIS OF OUTBOARD MOTOR EXHAUST WATER OBTAINED FROM OPERATION OF 4-HP MOTOR IN LAKE ONTARIO WATER AFTER INCUBATION FOR ABOUT 14 DAYS

RUN NUMBER	SAMPLE NUMBER	CONCENTRATION OF CHLOROPHYLL A, ppb[1]			
			EXHAUST WATER DILUTION RATIO[2]		
		CONTROL	1:100	1:10,000	1:100,000
15	A	5.7	2.1	7.9	7.5
	B	7.0	1.5	8.9	6.5
	C	6.5	1.9	--	--
16	A	7.0	3.5	15.0	9.4
	B	4.8	2.4	9.0	7.9
	C	4.4	2.7	10.0	9.9
17	A	6.6	13.0	11.0	5.6
	B	8.4	6.4	12.0	--
	C	6.5	12.0	9.6	9.5
18	A	43	10.0	44	60
	B	240	7.5	36	20
	C	150	7.6	46	34
19	A	82	8.8	31	32
	B	84	7.4	36	27
	C	25	7.2	26	32
20	A	24	7.6	45	36
	B	40	4.6	24	35
	C	56	5.2	39	41

Note: 1. Parts per billion.
2. Exhaust water dilution ratio gives the ratio of fuel used to dilution water. The control and diluent water were obtained from Lake Ontario along with water used in test tank.

6.3 ALGAL GROWTH EXPERIMENT

To determine the effect of outboard motor exhaust products on algal growth, the chlorophyll a results shown in Table VI were examined statistically at the 5 percent significance level, using the two-tailed "Student's -t" distribution test, to determine whether or not the concentrations measured are significantly different at the three dilution levels compared to the controls. The six test runs made on the 4-HP motor were separated into two test series depending on the operation of the motor and the dilution water used. Runs 15, 16 and 17 (first test series) were made using a pollution control device and runs 18, 19 and 20 (second test series) were made with the motor operating as it would under normal operation. The water used for the first test series was obtained from Lake Ontario on November 12, 1971; the water used for the second test series was obtained from the same location in Lake Ontario on November 26, 1971.

From the results shown in Table VI for the first test series, the concentration of chlorophyll a in the control samples is not significantly different from the concentrations measured at the 1:100 fuel-to-water dilution ratio whereas the chlorophyll a results are statistically significantly greater at dilutions of 1:10,000 and 1:100,000 compared to the control samples. On the other hand, for the second test series, the concentration of chlorophyll a in the control samples and at the 1:10,000 and 1:100,000 dilutions is not significantly different. In the tests at the 1:100 dilution however, the concentration of chlorophyll a is

significantly less compared to the other test samples.

Based on these data it would appear that the effect of exhaust products on algal growth depends on the quantity of water diluting the exhaust materials. In general, the results indicate that algal growth, as measured by chlorophyll a, is not adversely affected in samples of Lake Ontario water in which the 4-HP motor was operated. However, the results obtained at the 1:100 dilution ratio in the second test series indicate that there is some inhibitory effect on algal growth when the fuel use level is unusually high. The factors causing the retardation in the growth of algae were not investigated, but it could be attributed to certain toxic compounds such as volatile hydrocarbons, lead or phenols. This effect was not evident in the first test series at the 1:100 dilution ratio indicating that any adverse effects on algal growth could be reduced or eliminated with the use of a pollution control device.

From the data in Table VI it will be noted that the growths of algae in the control samples was relatively high during the second test series (run 18, 19 and 20) compared to the first test series (runs 15, 16 and 17). Because of this difference, the nutrient results shown in Table IV were examined statistically to determine whether or not the concentration of nutrients contained in the respective water samples is significantly different. Based on these data, the phosphorus level in the control samples from the second test series is statistically significantly greater compared to the level in the controls from the first test whereas

TABLE VII

ENUMERATION AND IDENTIFICATION OF ALGAE PRESENT IN EXHAUST WATER OBTAINED FROM 4-HP MOTOR (RUN 20) AFTER INCUBATION

IDENTIFICATION OF ALGAE SPECIES	DISTRIBUTION IN POPULATION EXPRESSED AS PERCENT OF TOTAL COUNT		
	EXHAUST WATER DILUTION RATIO		
	CONTROL	1:100,000	1:10,000
Scenedesmus	35	48	24
Ankistrodesmus	8	10	9
Gloeocystis	13	16	39
Chloococcus	44	26	28
Total Count, asu/ml	77,330	89,190	80,080
Chlorophyll a, ppb	40	41	39

organic nitrogen and organic carbon levels are not significantly different.

In addition to the chlorophyll a measurements, an algal enumeration and identification was made on samples of exhaust water from run 20 to ascertain whether or not there was any change in the algal population during the growth experiment.

In general, Scenedesmus, Ankistrodesmus, Glococystis, and Chloococcus, were the predominant algae although from the results shown in Table VII it appears that the population distribution at the different dilution levels was changed. Scenedesmus and Chloococcus species were more prevalent in the control and at the 1:10,000 dilution. The percent Ankistrodesmus did not change during the incubation period.

6.4 BELWOOD LAKE STUDY

The results reported in Table VIII indicate the concentration of CCE materials in Belwood Lake water decreased during the study period and do not show any deterioration in water quality over the summer boating season, if based on CCE material. It should be stressed however, that the water level in Belwood Lake varied by over 20 feet during the study period and it was difficult to maintain a constant sampling depth relative to the water surface. As was mentioned earlier, hydrocarbons (oils) are mostly insoluble in water (hydrophobic) and thus tend to separate and accumulate on the surface. Because of the sampling problem, the CCE results shown in Table VIII may not represent actual surface water quality and, thus, the overall condition in Belwood Lake is not necessarily reflected in these data.

TABLE VIII

WEIGHT OF CARBON CHLOROFORM EXTRACTS (CCE)
RECOVERED FROM SAMPLES OF BELWOOD LAKE WATER

SAMPLING LOCATION	SAMPLING PERIOD	WATER VOLUME EXTRACTED (litres)	CCE MATERIAL RECOVERED (grams)	CCE CONCENTRATION (mg/l)
SHAND DAM	July 7 - July 21	4086	0.74	0.181
	July 21 - Aug. 11	3178	0.40	0.126
	Aug. 17 - Aug. 26	5897	0.36	0.061
	Aug. 26 - Sept. 2	10674	1.02	0.096
PRIVATE DOCK	Aug. 6 - Aug. 20	740	0.62	0.838
	Aug. 20 - Sept. 2	1616	0.49	0.303

7.0 DISCUSSION

The various additives contained in gasoline and lubricants used in two-cycle outboard marine engines are another potential source of water contaminants. Almost all outboard motors used today are two-cycle models in which the lubricating oil is added to the gasoline. Mixture ratios in general use range from 15 parts gasoline to one part oil to a 50:1 ratio. The make-up of these oils is approximately 70 percent straight run mineral oil, 20 percent solvent (a heavy gasoline fraction similar to kerosene), and 10 percent additive. (17, 18) Since the exhaust from these motors is normally discharged into the water, all of these components are potential water pollutants.

Because a portion of the lubricant is burnt with the gasoline, two-stroke engines require different lubricants than four-cycle engines. With the lighter 40:1 and 50:1 mixture ratios which are used in two-cycle outboard marine engines manufactured in recent years, an ashless formulation is used. (17-19) Metal components, including compounds of barium, calcium, phosphorus, and zinc, are not used and are present as contaminants only. Certain specific additives contained in four-cycle lubricating oils, such as zinc dithiophosphate compounds, an anti-oxidant and extreme pressure additive, and ethylene dibromide which is used to improve the scavenging of lead deposits from the combustion chamber, are not generally used in lubricating oils for two-cycle outboard marine engines. The only lead scavenging additives used in the fuel mixture are those present in the gasoline. Also, detergent additives, such as barium and calcium sulphonate compounds, and viscosity index

improvers normally used in four-cycle lubricants are not considered necessary. The special additives used in two-cycle lubricating oils are mainly organic nitrogen compounds such as succinimide which is used as a dispersant to keep contaminants in suspension; these oils average approximately 0.8 percent by weight nitrogen. In addition, some premium two-cycle lubricating oils use a pour depressant to lower the pour point. Therefore, except for organic nitrogen compounds, the potential water pollution hazards associated with additives contained in lubricating oils used in most late model two-cycle outboard motors is negligible.

Lubricating oils used in the heavier fuel mixtures (17:1, 25:1 ratios etc.) used in earlier model two-cycle outboard motors do however, contain some metal components. (17) These oils may contain up to 0.07 percent zinc dithiophosphate compound, up to 0.5 percent calcium sulphonates and trace amounts of rapeseed oil, a 'slipperiness' additive. There are no data available that indicate the proportion of earlier model motors, however, as the number of motors using the heavier fuel mixtures become less prevalent the potential water pollution hazards arising from the use of these additives should become negligible. In general outboard motors have approximately a 10-year obsolescence period.

Until recently, the type of gasolines used in Ontario for marine purposes have been mainly regular grade, leaded automotive gasoline and marine white gasoline. Additives used in automotive gasoline usually consist of anti-oxidants and metal

deactivators to prevent the formation of gum, anti-icing compounds such as iso-propyl alcohol, and certain metallic compounds such as tetraethyl lead (TEL) and tetramethyl lead (TML) to increase the anti-knock value (octane rating). On combustion, these lead compounds form a non-volatile oxide which is deposited in the combustion chamber. To counteract this, 'scavenger' compounds such as tricresyl phosphate, ethylene dibromide and ethylene dichloride are added to promote vapourization of these lead deposits and to convert the lead, on combustion, into the relatively volatile lead bromide and lead chloride which pass out with the exhaust gases. Marine white gasoline is somewhat different from automotive gasoline and most of these additives are not used. (17, 19) Depending on the required octane level, leaded automotive gasoline may contain up to 8.0 gm lead additive per gal. equivalent to 0.23 percent by weight. (20) Marine white gasoline generally contains less than 1.3 gm lead additive per gal. To maintain the octane rating above 92 without requiring larger amounts of lead additive and to improve combustion, more pure, light-end straight-run, liquid petroleum products are used in marine gasoline compared to automotive gasoline. In 1971, it is estimated that approximately 10.7×10^6 gal. (49×10^6 l) of marine white and regular gasoline were sold in Ontario for marine purposes and it is estimated that over 50 percent consisted of marine white gasoline.

Recently there has been a decline in the use of marine white and regular gasoline for marine purposes due to the availability of low-lead and lead-free automotive gasolines and it is expected that further declines will occur. Low-lead and lead-free gasolines contain less than 0.8 and 0.06 gm lead additive per gal. With the decline in the use of lead additives, there has been a corresponding decline in the use of phosphorus additives. Lead-free gasolines generally contain less than 0.006 gm phosphorus per gal. The trend to producing gasoline without phosphorus and lead additives and their use for marine purposes represents an important reduction of water contamination caused by outboard engines.

7.1 Quantity of Exhaust Material From Outboard Motors

The tests made using modified engines to measure the amount of fuel wastage indicate that an increase in engine speed reduces the percent wastage of unburned fuel. They also indicate that the amount of fuel wastage varies greatly with motors of different manufacture and model. These results confirm those of others for similarly sized engines. (1-5)

The chemical results of the tank tests are summarized in Table IX showing gross loading data for engines operated both with and without a pollution control device installed. These data indicate that the quantity of contaminants discharged from operating two-cycle outboard marine engines can be significantly reduced by incorporating a control device to prevent the discharge of crankcase drainage into the receiving water.

7.1.1 Hydrocarbons

The indicated average values for non-volatile and volatile hydrocarbons (oils) show a reduction of over 80 percent in the gross loading of total hydrocarbons when the motors were modified to divert the crankcase drainage. The discharge of hydrocarbons in the exhaust is important because conventional water treatment processes do not completely remove these compounds. Laboratory experimentation conducted by the Research Branch on the effects of spills of raw fuel has shown that 420 gm (approximately 1 cupful), under ideal contaminant conditions will spread over approximately 1,800 sq. ft. (200 m^2) and under ideal spreading conditions, over approximately 5 acres. This slick would be easily visible and surface water would exceed the threshold odour limit of 10 ppb at 60°C by about 20 times. The presence

TABLE IX

AVERAGE QUANTITY OF EXHAUST MATERIALS CONTAINED
IN OUTBOARD MOTOR EXHAUST WATER,
(grams/gal. fuel consumed)

	HYDROCARBONS (oils)					NUTRIENTS		
OPERATING CONDITIONS	NON-VOLATILE	VOLATILE	LEAD	PHENOLS	COD	PHOSPHORUS	ORGANIC NITROGEN	ORGANIC CARBON
STANDARD[1]	105.3	123.	< 0.98	2.18	< 594	0.058	0.20	246.
MODIFIED[1]	20.2	21.3	< 0.66	0.92	< 227	0.034	0.285	71.6

NOTE: 1. Multiply by 0.1 to obtain grams per HP-hour.

of an oil on the surface may be objectional from an esthetic standpoint. However, water intake structures normally are submerged and because of the tendency of these compounds to accumulate in the surface layers, they would not likely be experienced at the water treatment plant except at very low concentrations.

The volatile hydrocarbons are generally unstable in the aqueous plase because of their low boiling point and therefore will tend to evaporate. Also, biodegradability studies conducted by Shuster (14) demonstrated that engine fuel (50:1 ratio) as well as exhaust products are biodegradable and therefore the persistence of these compounds will depend on the waste assimilation potential of the receiving water. Although no data was found in the literature concerning the degradation rates of outboard motor exhaust products, the results of field studies by English et al. (7) and Kempf et al. (9) demonstrated natural self-purification phenomena. In pond tests they found that when motor operation was discontinued the general quality of the water improved progressively with time as a result of self-purification. The results reported by Environmental Engineering, Inc. (15) also demonstrated natural assimilation of exhaust products in a lake system.

7.1.2 Phenols

The discharge of phenolic substances is undesirable. They are not removed by conventional water treatment processes and as little as 0.002 mg/l of phenol can cause a perceptible taste when chlorinated. (12) According to the criteria for water quality adopted by the Ministry of the Environment, phenolic

substances should be virtually absent in public surface water supplies. From the data shown in Table IX it will be noted that, when the motors were operated without modification, approximately 2.18 gm of phenols was discharged into the water per gal. of fuel consumed (approximately equal to 0.5 gm/l fuel consumed). Without allowing for biological degradation, this quantity requires approximately 1.8 acre-feet (2220 m^3) of water for dilution to an acceptable level if based on a phenol concentration of 0.001 mg/l. When a control device was installed to collect the crankcase drainage, the discharge of phenols was reduced approximately 58 percent to about 0.92 gm per gal. of fuel consumed.

Phenols generally are biodegradable and therefore the net accumulation of phenolic substances during a boating season would be reduced by an amount depending on their decomposition by natural purification processes. Based on the influence of exhaust products on the flavour of fish determined through field tests, a permissible fuel consumption of 1.36 gal. per annum per acre-foot (5 $l/10^3 m^3$) of water is indicated. At an average fuel consumption rate of 0.1 gal. per HP-hr, this corresponds to a motor use level of 13.6 HP-hr per annum per acre-foot (3.7 HP-hr/$10^3 m^3$/year). If it is assumed that natural purification phenomena limit the accumulation of phenolic substances to a 30-day period, and based on the loading data in Table IX, the concentration of phenols in receiving water in which outboard motors are operated would be less than 0.001 mg/l at the motor use level that will not produce tainting of fish flesh (13.6 HP-hr/acre-foot/year).

7.1.3 Lead

Lead is toxic and because the metal becomes bound as an oxide and tends to accumulate, its discharge in the exhaust from outboard motors is undesirable. The acute toxicity of lead is dependent upon whether the metal is present as inorganic lead or an organo-metallic compound such as tetraethyl-lead. The analysis of samples of exhaust water obtained from runs made using the 40- and 4-HP motors indicated the organic lead content at a dilution level equivalent to 450 gal. of fuel consumed per acre-foot of water was less than 0.01 mg/l, which is 1/20 of the TLm value indicated by Eckenfelder. (11)

Lead is not removed from water by conventional water treatment processes and according to the water quality criteria adopted by the Ministry of the Environment, public surface water supplies should not contain lead in excess of 0.05 mg/l. From the gross loading value in Table IX, since about 2.0 gm lead is contained in one gal. of regular gasoline (0.44 gm/l), about 49 percent of the lead contained in the original fuel mixture was discharged in the exhaust as inorganic lead. Even assuming 100 percent of the lead content is discharged in the exhaust, the level of fuel use that is required to reach a lead concentration of 0.05 mg/l is approximately 50 times the level that will produce tainting of fish flesh. With late model engine designs, outboard motor manufacturers are recommending low-lead or lead-free gasoline thereby eliminating this potential water pollution hazard.

7.1.4 Nutrients

Based on nutrient loading data indicated in Table IX, the quantities of organic carbon, organic nitrogen and phosphorus discharged into the receiving water is very small. At the motor use level indicated to prevent the tainting of fish, the increase in the organic nitrogen and phosphorus content in a receiving water would be less than 1.0×10^{-4} mg/l. Compared

to a minimum concentration of 0.02 mg/l total phosphorus and 0.20 mg/l organic nitrogen contained in most surface waters, the increase in concentration of these nutrients due to motor operation is not significant. The discharge of organic carbon in the exhaust (0.007 pounds per gal. fuel consumed or 0.07 gm per litre of fuel) is also considered insignificant. In addition, outboard motor manufacturers are recommending gasoline without phosphorus additives which should reduce phosphorus inputs. The increase measured in inorganic carbon is likely due to the entrainment of carbon dioxide (CO_2) during turbulent mixing of the water in the test tank and is consistent with corresponding decreases in pH (Table IV). When the 40- and 9.5-HP motors were operated in idle (runs 1, 4, 7 and 10) the changes both in organic carbon and pH results were small compared to results obtained for runs made with these motors engaged in gear.

7.2 Effects of Exhaust Materials from Outboard Motors

Fuel consumption per unit volume of water is the most meaningful parameter readily available for establishing safe levels of outboard motor activity. A summary indicating safe limits for fuel consumption that will not unduly affect the quality of water for different uses is shown in Table X. The limit indicated for odour control is based on a maximum increase of 4 in the threshold odour number (TON) of the receiving water. Results of tank tests made using the different motors without modification indicated the discharge of exhaust materials into the water from the combustion of 1.36 gal. of fuel per acre-foot (5 $l/10^3 m^3$) increased the TON of the diluent water to between 8 and 64. Except for run 14 made using the 6-HP motor, the TON was increased to between 3 and 4 at a level of 0.27 gal. of fuel consumed (1.0 $l/10^3 m^3$) per acre-foot, the level indicated by English et al. to control odour. For run 14,

the TON increased to 16 at this dilution level. With the same motors modified to prevent the discharge of crankcase drainage into the water in the test tank the TON increased to 8 at a level of 1.36 gal. of fuel consumed per acre-foot (5 $l/10^3m^3$). A TON over 3 is considered as objectionable to most people.

Changes in threshold odour levels of water in which outboard motors were operated were also determined using lake water with a 'natural' odour as the diluent. Samples were prepared using Lake Ontario water of fuel-to-water ratios equivalent to 0.27 and 1.36 gal. of fuel consumed per acre-foot of lake water (1.0 and 5 $l/10^3m^3$, respectively). Using water in which the outboard motor was operated at a level equivalent to 0.27 gal. per acre-foot (1.0 $l/10^3m^3$) without modification, the odour of the lake water increased from a baseline TON level of 8 to 16 which is equivalent to one dilution. At the 1.36 gal. per acre-foot fuel-use level, the TON increased from 8 to 128 which is equivalent to four dilution levels. Using exhaust water obtained when the 9.5-HP motor was modified, the odour number of the lake water increased from 8 to 16 and 64 respectively, at fuel-use levels of 0.27 and 1.36 gal. per acre-foot. These increases in threshold odour levels are comparable to the changes indicated when odour-free water was used as the diluent.

The maximum estimated concentration of certain exhaust materials in receiving water at the fuel use level indicated both for odour control and to avoid tainting of fish flesh is shown in Table XI, without allowing for natural assimilation of

TABLE X

SAFE LIMITS FOR FUEL CONSUMPTION THAT WILL NOT UNDULY AFFECT THE QUALITY OF WATER FOR SELECTED USES

DAMAGING EFFECT	BASIS FOR LIMITS	REFERENCE	SEASONAL FUEL USE LEVEL[1]
Odour	Level that will not unduly affect odour quality of water for use as a domestic supply	English (6)	0.27
		Author	0.27
Toxicity to fish	An arbitrary application factor of 1/100 of the 96-hour TLm is used as the criterion	English (6)	1.43
		Kempf (9)	0.90
Tainting of fish flesh	An arbitary application factor of 1/2 of the fuel use level that will produce tainting is used as the criterion	English (7)	1.10
		Kempf (9)	1.36
Algal growth	Level that will not stimulate growth of algae	Author	1.36

NOTE: 1 (a) Fuel use levels shown are for a 60-day boating season and are expressed in gal. of fuel per acre-foot of receiving water.

(b) Multiply by 10 to obtain HP-hr per acre-foot of receiving water.

TABLE XI

AVERAGE CONCENTRATION OF EXHAUST MATERIAL IN RECEIVING WATER AT TWO FUEL USE LEVELS, mg/l

EXHAUST MATERIAL	FUEL USE LEVEL, gal./acre-foot*				PERMISSIBLE CRITERIA
	STANDARD		MODIFIED		
	0.27	1.36	0.27	1.36	
TON	3-4	16-64	1.5-2	8	3**
Non-volatile oils	0.023	0.115	0.0044	0.022	virtually
Volatile oils	0.027	0.134	0.0048	0.023	absent
Lead	0.00021	0.0011	0.00014	0.0007	0.05
Phenols	0.00048	0.0024	0.00020	0.001	0.001***
CCE	<0.10	<0.3	<0.05	<0.10	0.15

NOTE:

* Multiply by 3.685 to obtain $1/10^3 m^3$.

** A TON over 3 is considered as objectional to most people.

*** U.S. Federal Water Pollution Control Administration surface water criteria for public water supplies.

the contaminants. The permissible water quality criteria for public surface water supplies is also indicated for comparison. It will be noted that the exhaust materials contained in the receiving water at the fuel use level indicated to control odour, the critical use level, are within allowable limits that should not unduly affect the quality of the water for use as a domestic supply. However, as was indicated earlier, at a seasonal fuel use level of 1.36 gal. per acre-foot (5 $l/10^3 m^3$) for a 60-day boating season, the total quantity of exhaust materials discharged into the receiving water exceeds the quantity required to reach the permissible criteria. While it will be recognized that each watercourse has a definitive self-purification capacity, nevertheless the ability of the particular watercourse to assimilate wastes and to restore its own quality should be considered when establishing limits for motor use consistent with water use objectives. One report indicated that, in a naturally aerated lake, organic materials discharged into the water from an outboard motor were 80 percent biologically degraded within 7 days. (22) If it is assumed that the waste assimilation capacity of a receiving water limits the accumulation of organic materials discharged into the water to a 12-day contribution, then the maximum concentration of contaminants experienced during a 60-day boating season should not exceed the permissible criteria for public surface water supplies at the motor use level recommended to avoid tainting of fish flesh. When the motors were operated with a pollution control device to divert the crankcase drainage, the concentration of the various contaminants in the dilution water did not exceed the permissible criteria at the level indicated to avoid fish tainting.

The safe limit for fuel use shown in Table X that will not unduly affect the growth of algae was determined based on an arbitrary application factor of 1/2 of the fuel-to-water dilution ratio that would not stimulate the growth of algae. This limit corresponds to a dilution ratio of 1:200,000 and is equivalent to 1.36 gal. of fuel consumed per acre-foot of water (5 $l/10^3m^3$).

7.3 Use of Outboard Motors in Ontario

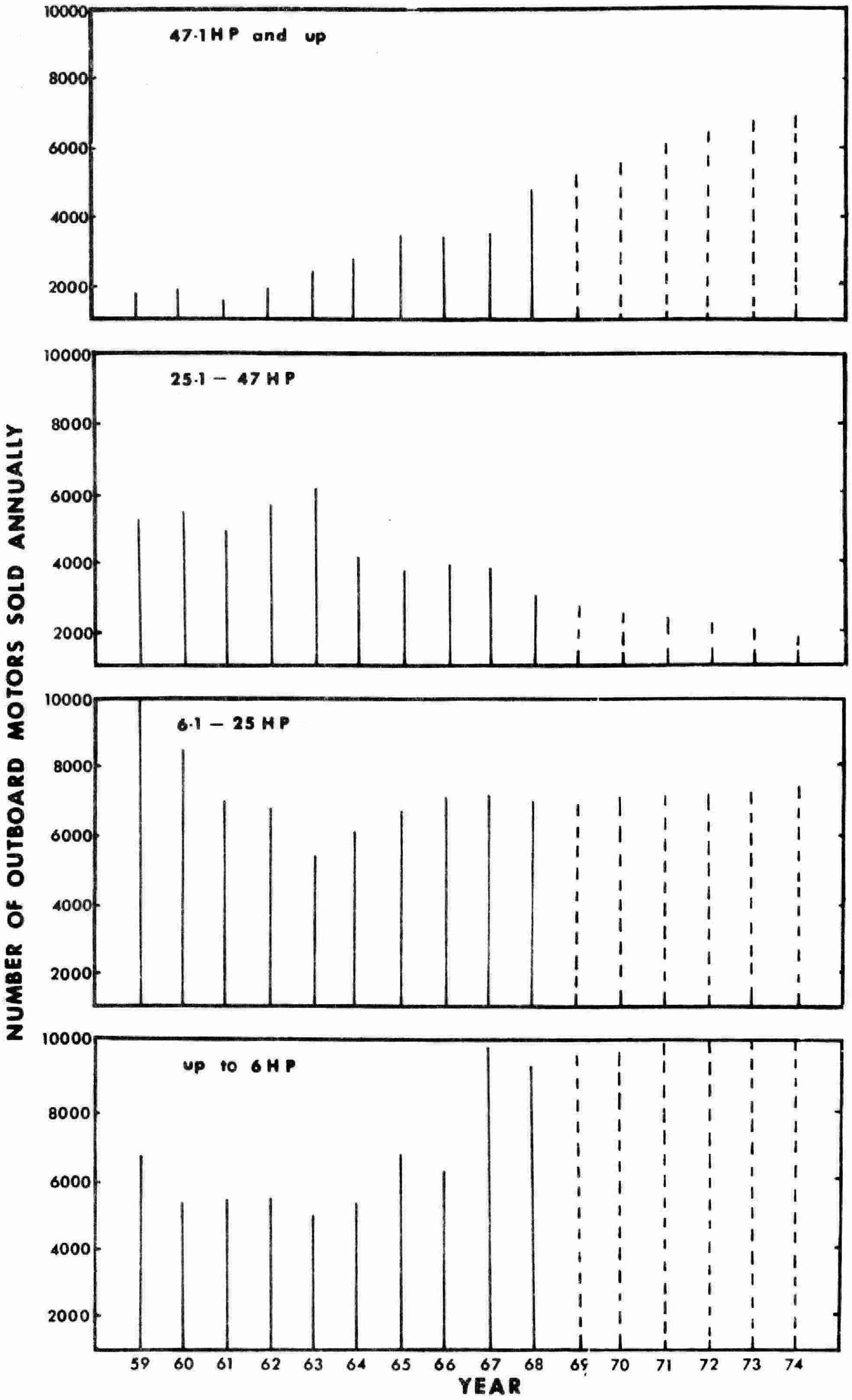
According to figures compiled by the Allied Boating Association of Canada, (21) there were an estimated 206,560 outboard motors in use in Ontario during 1968, having an average engine size of 22.5 HP. This represented an increase in total units of about 0.8 percent compared to 1967 figures if based on a 10-year obsolescence period. Figure 5 shows a summary of sales data for the period from 1959 to 1968 according to engine size. Outboard motor sales projections for the next six year period through 1974 indicate that at the beginning of the 1975 model year (October 1, 1974) there will be an estimated 235,000 outboard motors in operation in Ontario with decreases in the share of the market posted by motors in the middle (25-47) horsepower range. The change in market distribution is illustrated in the following figures:

HORSEPOWER RANGE	PERCENT 1959-68	PERCENT 1959	PERCENT 1968	PERCENT 1974
0-6.0	32	28	39	40
6.1-25.0	35	42	29	28
25.1-47.0	23	22	12	6
47.1 and up	10	8	20	26
Total Units	206,560	22,894	23,558	26,050

This redistribution is not expected to bring any significant change in the average horsepower outboard motor sold in 1974 compared to 1968 models (average 22.0 HP).

Announcements by the three major outboard motor manufacturers, representing over 95 percent of the outboard motor market, indicate all 1972 models incorporate systems to recirculate any unburned fuel that collects in their induction systems. (23) The discharge of 'excess' fuel has been eliminated by a check valve system that returns unburned fuel to the combustion chamber. Based on the tank test results this should eventually reduce the gross loading of contaminants contributed by two-cycle outboard motors by from 50 to over 80 percent. Also, low lead gasoline without phosphorus additives is now manufactured for marine use which should further reduce the amount of contamination due to outboard motor use.

From the sales projection figures shown in Figure 5 it may then be estimated that about 32 percent of all outboard motors in use in 1974 will be 'drain-free' designs that recirculate unburned fuel. This means that an estimated 160,000 outboard motors (68 percent) in use in Ontario at the end of the 1974 boating season will not be affected by these design changes and it is estimated that it would take a minimum of 10 years to replace these current model outboards with drain-free models, if based on a 10-year obsolescence. Unless these motors are modified to divert the fuel normally wasted from the crankcase, they will continue to discharge unburned fuel into the receiving water thus creating potential water pollution hazards.



Projection — — — — —

Number of outboard motors sold annually in Ontario for the 10 year period 1959 to 1968 with sales projection figures for the 6 year Period 1969 to 1974.

FIGURE 5.	Feb. 1972	jmcg

Proprietary devices are manufactured as an attachment for outboard motors that redirect the normally wasted fuel into the fuel system thereby eliminating the discharge of crankcase drainage into the water. Reports by others indicated that under idling conditions, one device returned over 30 percent of the fuel drawn in by the engine and the motor operating efficiency was increased by from 20 to 30 percent, depending upon running speed; the running time was found to be 41.7 to 68.8 percent greater than the running time without the device. (3) The concentration of oil in the fuel mixture remaining in the feed tank was found to remain unchanged while the motor was running, and to increase by an amount considered insignificant when the motor was stopped. Another report indicated that these devices do not work after repeated tankfuls of fuel in which cumulative drainings have been collected and recycled through the engine. (22) These devices can be readily installed on some engine models; there are some makes that must be disassembled to make the attachment. Some models in the low horsepower range (up to 6-HP) must be rebuilt to make the necessary modifications. Based on the increase in operating efficiency indicated, it has been reported that the cost of installing one of these units on most motors would normally be recovered through savings on fuel in one or two boating seasons, depending on the amount of fuel used per season. (3)

8.0 CONCLUSIONS

From the results of this study it is concluded that:

The results of laboratory tank tests which are supported by the findings of English et al. (6, 7) show that the operation of two-cycle outboard marine engines represents a potential source of pollution of lakes and rivers. The major determinants regulating safe levels of outboard motor activity are the quantity of water diluting the exhaust materials and the natural self-purification capacity of the receiving water.

The results of tank tests made with two-cycle engines modified to divert crankcase drainage normally discharged into the water show that the amount of unburned fuel wasted ranged from less than 1 percent to over 27 percent of the original fuel drawn by the engine, varying with motor models and engine speed.

The laboratory tank test results indicate that non-volatile hydrocarbons (oils), lead, phenols, COD and organic carbon were the primary contaminants discharged in the exhaust from two-cycle outboard motors.

The most significant problem owing to two-cycle outboard motor activity appears to arise from the effect of exhaust products on water odour and in the tainting of fish flesh. Therefore, any regulation to establish acceptable levels of

outboard motor activity to be allowed on recreational waters should be based on the possible damaging effects on the use of the water as a source of domestic water supply and on the damage to fish stock.

Because of the ability of a water course to assimilate wastes and restore its own quality, the self-purification capacity of individual lakes and rivers used for recreational motor boating must be determined before levels of outboard motor activity that will not unduly affect the quality of that water for different purposes may be established.

The limit for motor use to avoid tainting of fish flesh corresponds to a fuel-use level of 1.36 gal. per acre-foot (5 $l/10^3m^3$) for a 60-day boating season. The limit that will not unduly affect odour quality of water for use as a domestic supply, the critical parameter, corresponds to a fuel-use level of 0.27 gal. per acre-foot (1.0 $l/10^3m^3$).

The limit for fuel use that will not unduly affect the growth of algae corresponds to a fuel-to-water dilution ratio of 1:200,000, which is equivalent to the dilution limit indicated to avoid fish tainting (1.36 gal. per acre-foot).

The laboratory tank test results show that eliminating the discharge of unburned fuel will reduce the gross loading of contaminants contributed by two-cycle outboard motors by from 50 to over 80 percent. Announcements by the three major outboard motor manufacturers representing over 95 percent of the outboard motor market, indicate all post-1971 models will

incorporate systems to recirculate unburned fuel that collects in the induction system. Under these circumstances, as the prevalence of "drain-free" motors increases, levels of motor use that will not unduly affect the quality of water should increase substantially.

The spillage of quantities of gasoline and oil is inevitable wherever there is outboard motor activity. Because of the damaging effect of outboard motor fuel and exhaust products on water odour, it may be necessary to strictly regulate or prohibit motor activity on stationary waters such as reservoirs used to impound or store water intended primarily for domestic purposes.

9.0 RECOMMENDATIONS

As a result of the foregoing study it is recommended that:

1. Without specific local information to the contrary, the use of two-cycle outboard motors on recreational lakes and rivers should be limited to such as to not exceed a fuel-use level of 1.36 gal. per acre-foot (approximately equal to 13.6 HP-hr per acre-foot) for a 60-day boating season. In order to implement this recommendation it is necessary that, in areas of obvious concern, the Ontario Ministry of the Environment determine actual use, and where practicable, implement limitations as required.

2. The recreational use of two-cycle outboard motors should be prohibited on bodies of water used to impound or store water intended primarily for domestic purposes. Such limitation may be implemented under existing legislation or an amendment as required.

3. As the prevalence of drain-free motors increases any limits on the use of two-cycle outboard motors that may be established should be reviewed to reflect the reduced levels of contamination from these motors.

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